# A new copper alloy for utility condenser tubes

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**Adding more nickel and small amounts of other alloying elements to the 90/10 copper alloy now commonly used in condenser tubing appears to hold considerable promise for cooling systems using seawater. Erosion-corrosion effects are reduced, while other beneficial properties are retained**

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Many changes in the pattern of heat exchanger tube selection for condensers installed in new electric generating steam power plants have occurred in the past decade. These changes have been toward the use of fewer types of materials and thinner wall gages, as well as a general upgrading of material, with a shift away from the older traditional alloys.

In the copper family, the copper-nickel alloys have gained predominance. Even when admiralty is specified for the steam surface condenser main body, 70/30 copper-nickel is likely to be used in the air removal zone and is quite often specified for impingement zones as well. However, the most frequently specified material for general use has become 90/10 copper-nickel, alloy C70600.

Data to be found in the annual report of the Committee on Power Generation of the Association of Edison Illuminating Companies show that in 1980 over half the tubing specified (based on surface area) in orders placed for new condensers was copper-nickel.

The market share trend lines for the major types of heat exchanger tube materials from 1961 to 1980 are shown in Figure 1. The following conclusions can be drawn:

1. Copper, including arsenical copper, alloy C14200, and the copper-iron alloy C19400, has had a minor share of the market and shows a slightly negative slope in usage.
2. Aluminum brass has declined to the point where the last order for a new generating station specifying it was placed in 1974.
3. Titanium has increased its market share slightly over the period from 1971 to 1980.
4. Admiralty, long the most frequently specified condenser tube alloy for freshwater service, has largely been replaced by stainless steel and copper-nickel.
5. Stainless steel has shown increasing usage from 1961 to the present.
6. Copper-nickel, mainly 90/10, alloy C70600, has grown in use to the point of

**Table 1.** Composition limits and tensile requirements for alloy C72200 used in condenser tubes per ASTM B-111

| Element | Nominal - % | Range - % |
|---|---|---|
| Copper (incl. silver) | Balance | 79.3 min |
| Nickel (incl. cobalt) | 15 | 15.0 - 18.0 |
| Lead | — | 0.05 max |
| Iron | 0.8 | 0.5 - 1.0 |
| Manganese | 0.5 | 1.0 max |
| Zinc | — | 1.0 max |
| Chromium | 0.5 | 0.3 - 0.7 |

Note: The total of copper plus these six elements with specific limits equals 99.5% min.

| Temper | Tensile strength (min) ksi | Tensile strength (min) MPa | Yield strength (min) ksi | Yield strength (min) MPa | Elongation in 2- inch (50.8 mm) % min |
|---|---|---|---|---|---|
| Annealed | 45 | 310 | 16 | 110 | 40 |
| Light drawn | 50 | 345 | 45 | 310 | 20 |

**Table 2.** Nominal composition and material dimensions for tubing sample test

| Alloy | Composition (%) | OD (in.) | Wall th (in.) |
|---|---|---|---|
| C70600 90/10 CuNi | 10.1 Ni, 1.2 Fe, 0.50 Mn, bal Cu | 7/8 | 0.045 |
| C71500 70/30 CuNi | 29.7 Ni, 0.56 Fe, 0.47 Mn, bal Cu | 7/8 | 0.033 |
| C71640 70/30 CuNi | 30.0 Ni, 2.2 Fe, 2.2 Mn, bal Cu | 7/8 | 0.035 |
| C72200 85/15 CuNi + Cr | 17.2 Ni, 0.81 Fe, 0.57 Mn, 0.7 Cr, bal Cu | 7/8 | 0.046 |

**Table 3.** Erosion resistance under blockage conditions for 12-mo samples

| | | Maximum erosion at blockage (inches) | | | |
|---|---|---|---|---|---|
| Bulk velocity (fps) | Blockage velocity (fps) | C70600 | C71500 | C71640 | C72200 |
| 7 | 10.5 | 0.006 | 0.005 | 0.012 | nil |
| 11 | 16.5 | 0.020 | 0.008 | 0.019 | 0.006 |
| 14 | 21.0 | 0.030 | * | 0.036 | 0.008 |

*Holed through

**Table 4.** Field service trials for alloy C72200 in coastal utility service

| Utility | Service (yrs) | Maximum erosion at inlet (in.) |
|---|---|---|
| Gulf Coast "A" | 5.3 | 0.002 |
| Gulf Coast "B" | 5.6 | 0.003 |
| Gulf Coast "C" | 5.9 | 0.002 |
| New England "A" | 4.9 | 0.001 |
| East Coast "B" | 6.8 | 0.001 |
| West Coast "A" | 5.9 | 0.001 |
| West Coast "B" | 5.3 | 0.001 |

being the most frequenty specified condenser tube material in recent years.

A new alloy, designated C72200, has been developed in order to improve on the performance of the copper-nickel condenser tube alloys, especially for seawater service. The alloy is essentially 85/15 copper-nickel with additions of 0.5% Cr, 0.5% Mn, and 0.7% Fe. Composition limits and mechanical properties for this alloy, as specified in the American Society for Testing and Materials (ASTM) B-111, are shown in Table 1.

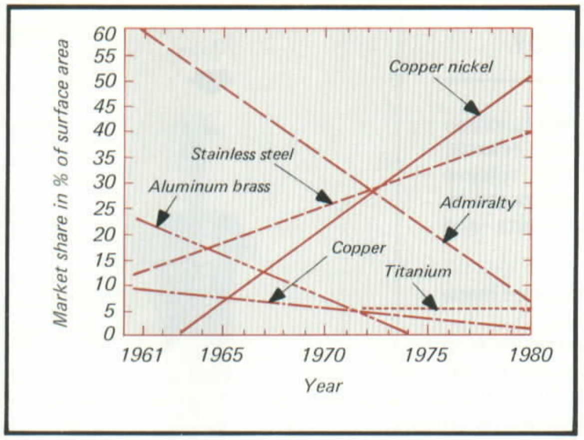


**Figure 1.** Smoothed trend lines showing market shares of specified condenser tube materials by surface area (new units only).

### Tests on alloy C72200

Copper-nickel alloys are considered superior performers in marine environments. As the nickel level is increased, the resistance of these alloys to erosion-corrosion also increases. Iron additions to the composition further improve erosion-corrosion resistance, as is the case with alloy C70600. Additional improvement is provided by alloy C72200, with its intermediate nickel level (15%) in combination with both iron and chromium.

Early laboratory testing of alloy C72200 demonstrated a marked increase in resistance to localized impingement or erosion-corrosion as a result of water flow, compared to alloy C70600. Controlled-velocity laboratory jet tests, confirming the generally accepted 10 fps limit for alloy C70600, showed alloy C72200 in comparison to have an apparent velocity limit of 20 fps, well beyond flow rates anticipated in normal service (Figure 2). This superiority is confirmed by shear stress calculations.

The optimum corrosion resistance of copper alloys in flowing seawater depends on the formation and retention of the normal thin protective oxide films on the inside surface of the tube. The shear forces in rapidly flowing seawater systems can damage these films and lead to localized impingement/erosion attack. While absolute shear stresses can vary with seawater temperature and other factors, comparisons among alloys are valid in the absence of any significant pollutants that could interfere with normal oxide film formation. The critical shear stress (between film and base metal) in lb/ft$^2$ for aluminum brass is 0.4; for 90/10 and 70/30 copper-nickel they are 0.9 and 1.0, respectively. Alloy C72200 shows a critical shear stress of 6.2, a value which has been shown to be above the shear loading to be expected in normal condenser service. This value is higher than those of similar alloys because of the addition of chromium. See Table 2.

Calculated maximum shear stresses in operating condensers as reported by a Japanese source for a 1-in.-diameter tube with seawater flowing in it at 7 fps are 0.4 lb/ft$^2$ at the inlet and a maximum of 5.5 at any blockage. The properties of alloy C72200 can be seen to exceed these requirements.

A group of copper-nickel alloys was evaluated under artificial blockage conditions in a seawater environment to confirm the characteristics of alloy C72200 under these conditions. The materials used were commercially produced tube samples from several manufacturers. All samples were ⅞-in. o.d.; alloy C71500 and C72200 tubes were seam welded; those of alloy C70600 and C71640 were seamless. Compositions and wall thicknesses are shown in Table 2.

The samples were cut to 12-in. lengths and the ends deburred. Vapor degreasing was carried out using trichloroethane, after which the samples were dried. Three test loops were constructed, each containing all the alloys in the series. The tubes with artificial blockages were located at alternating positions in the loops, separated with unblocked tubes to ensure that the turbulent effects associated with the blockages were smoothed out downstream prior to entering the next blocked tube. Tube samples were butted together, held in place with polyvinyl chloride (PVC) tubing, and secured with hose clamps.

The artificial blockages, illustrated in Figure 3, were constructed of PVC and nylon. The blockages were installed with the screw end facing the direction of flow. The two nylon balls, bonded to the PVC main structure, provided a uniform crevice. The "clothespin" design of the structure has been found to provide the necessary degree of turbulence; it was thus selected for this program. Installation was performed by expanding the legs of the clothespin by turning the brass screw. When the screw was fully tightened, the pressure exerted by the nylon balls on the tube walls was at the maximum.

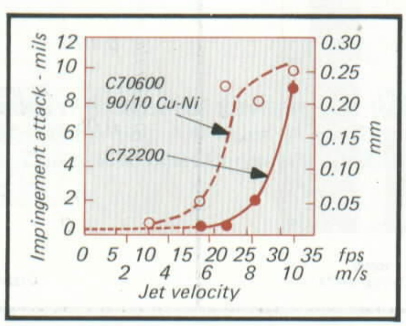


**Figure 2.** Velocity limits of alloys C70600 and C72200 as determined in 56-day laboratory jet impingement tests with seawater.

The artificial blockages were installed in the tube outlets. This ensures that the tee of the blockage, which locates and anchors it into the system, does not interfere with fluid flow around the nylon balls. When assembled, the blockages are held by the PVC hose connecting the tube samples, and movement does not occur.

Three bulk flow velocities were selected: 7 fps, representative of the majority of operating condensers and the velocity at which alloy C70600 has shown good performance in service; 11 fps, considered to be at the velocity limit for alloy C70600 but within the design limits of alloy C71500; and 14 fps, the maximum design limit of alloy C71500 and at a velocity at which alloy C70600 would show some metal loss from erosion.

The blockages partially restrict the tube bore and increase velocity by a factor of approximately 1.5. Velocity at the blockage is thus increased to 10.5, 16.5, and 21 fps, respectively, in each of the three test loops.

The test loops were installed in the Battelle Laboratories facility in Daytona Beach, Fla. Seawater was drawn by a submersible pump to a constantly overflowing reservoir, with each loop drawing from this reservoir. Centrifugal pumps and constant-flow controls were used to maintain loop flow velocities.

### Test results

The loops have completed a full year on test, with specimens removed after exposures of six and 12 months. The blockage test program confirmed, under realistic test conditions, the previous relative rankings of erosion resistance for the alloys based on laboratory data and calculations.

Several general observations were made after six months of exposure:

1. No blockage in the loops moved from its initial position. In many cases marine growth was attached to the PVC components. No marine growth was visible on the copper alloy tubing.
2. All parts of the tubes, irrespective of alloy or velocity, excepting the immediate inlet and blockage regions, were covered with the typical thin protective film.
3. Where erosion had occurred at the blockage, the typical horseshoe-shaped channel was seen around the nylon balls. The depth of this erosion-corrosion, not its extent, was considered as the measure of comparative material performance.

When the six-month samples were removed, they were replaced with additional blockage specimens. At the 12-month test point, both the second group of six-month samples and the continuous 12-month samples were removed.

Examination of the second group of six-month samples again confirmed the same alloy performance rank as the first group, with alloy C72200 having the best resistance to erosion and alloy C70600 the least. While comparative rank was the same, erosion rates were different, and the total amount of erosion-corrosion was more severe by a factor of two compared to the first six-month test group. The differences in start-up dates may be partially contributory, since seasonal temperature and water chemistry variations exist.

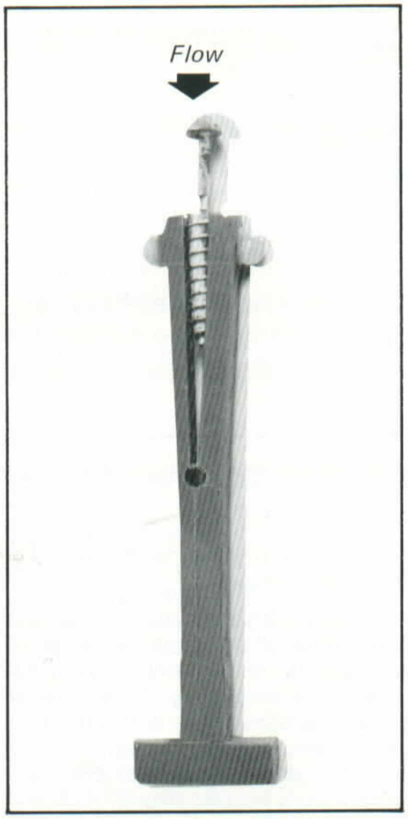


**Figure 3.** Artificial blockage device used in piping erosion testing.

The tests were intended to compare performance of the alloys, not to develop absolute data. (Previous experience with this test site had indicated only marginal seasonal variation in corrosion performance.)

The 12-month test group again demonstrated the superior performance of alloy C72200. Comparative erosion resistance ranking for the alloys, based on the 12-month data, are shown in Table 3.

## Field operating experience

Trial lots of both seamless and welded C72200 tubing were produced to permit service testing in coastal utility condensers. Seven test sites were selected based on past histories of inlet erosion problems with copper-based alloys. Table 4 summarizes the results of service exposures of five to seven years at the seven sites.

A short-term test in an aggressive 1000 ppm ammonia environment has demonstrated that the resistance of alloy C72200 is consistent with the performance of other copper-nickel alloys and reflects its 15% nickel content. These data are shown in Figure 4.

High loadings of abrasive sand in cooling water can destroy protective oxide films and lead to premature tube failure. Increased resistance to entrained sand would be particularly beneficial in desalting plants in the Middle East. Limited data (Figure 5) suggests some benefits can be obtained when using alloy C72200. An in-house program to provide more definitive data in this area is now in progress. Results to date confirm the previous rankings shown in Figure 5.

Copper alloy C72200, a chromium-modified copper-nickel alloy, has proved to be highly resistant to impingement-erosion attack in seawater service. The alloy appears to solve some of the problems of premature condenser tube failure associated with localized turbulence at tube inlets and downstream blockages.

In addition to its exceptional velocity tolerance, the alloy retains the following recognized benefits of other copper-nickel alloys: (a) excellent natural anti-fouling properties, (b) high thermal conductivity, (c) ease of fabrication, (d) resistance to corrosion by the condensate, and (e) galvanic compatibility with tube sheet and water box materials. **END**

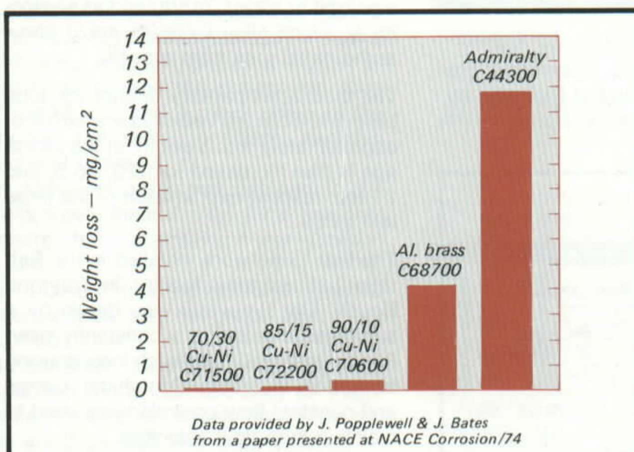


**Figure 4.** Relative ranking of alloys in accelerated 10-day ammonia test at a concentration of 1000 ppm.

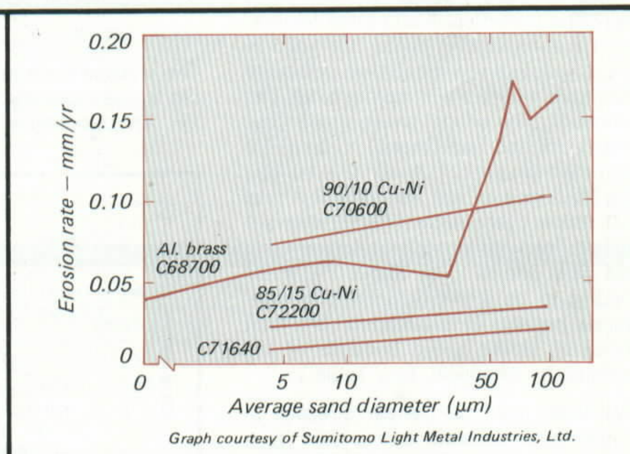


**Figure 5.** Relative rankings of alloy resistance to abrasion by sand-containing water. (Alloy C71640 is a proprietary formulation, basically 70/30 Cu-Ni.)